

ON CHEMICAL FRACTIONATION IN THE SILICATE PHASE OF METEORITES

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ON CHEMICAL FRACTIONATION IN THE SILICATE PHASE OF METEORITES*

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ABSTRACT

The content of lithophylic elements in stony and stony-iron meteorites of various types has been investigated.

The chondrites should be divided into three branches -- enstatite, ordinary and carbonaceous, with a varying content of both the total iron and its forms, and the relative nickel content.

It is evident from the data presented that there is a direct connection between the groups within each branch of chondrites. As regards the content of most of the elements, ordinary chondrites lie between enstatite and carbonaceous chondrites. No conclusion can be drawn as to the process of transition from one branch of chondrites to the other.

The peculiarities of the chemical composition of the silicate phase of meteorites cannot be explained by a single process of fractionation as, for example, the loss of volatile elements.

In meteoritic matter one may observe the fractionation of chemical /291** elements, caused by their distribution among the silicate, metallic, and other phases, and also fractionation within a given phase. The latter can be investigated by tracing the behavior of elements concentrated in a given phase.

In this report the author discusses certain problems connected with the chemical fractionation in the silicate phase of meteoritic matter, on the basis of recent data on the content of lithophylic elements in stony and stony-iron meteorites.

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**Numbers in the margin indicate pagination in the original foreign text.

In order to study the problem of chemical fractionation, one must examine first of all the differences in the composition of meteorites of various groups, and must then search for regular relationships among these groups which would indicate possible processes of change in their chemical content. In this connection the classification of meteorites (separating them into groups on the basis of various characteristics) and the systematization of these groups is of great importance.

As a result of recent investigations, the majority of authors at present divides the class of stony meteorites into three subclasses: chondrites, calcium-poor achondrites, and calcium-rich achondrites. At the same time the class of stony-iron meteorites is divided essentially into two subclasses: pallasites and mesosiderites. Within these subclasses, a distinction may be drawn between groups, which differ from one another primarily in the chemical and mineral composition.

We shall focus our attention on the most numerous form of stony meteorites, i.e., on chondrites. In our opinion, which is shared by some other authors, chondrites can be divided into eight groups: (1) enstatite of Indarkh type, (2) enstatite of Hvittis type, (3) bronzite, (4) hypersthenic, (5) amphoteric, (6) carbonaceous of Orgueil type, (7) carbonaceous of Migey type, and (8) carbonaceous of Felix type. In view of the absence of a single terminology for the designation of the groups, the names used by the author are given here, although we do not feel they are the most appropriate ones.

The next problem is the systematization of the chondrite groups. Urey and Craig (Ref. 1), having chosen the total iron content as the basic characteristic, divided chondrites into two fundamental branches: those with high iron content (H), and those with low iron content (L). The bronzite and enstatite chondrites were included in the H group, whereas the hypersthenic and amphoteric ones were assigned to the L group. Afterwards, Wiik (Ref. 2), and subsequently Ringwood (Ref. 3), Mason (Ref. 4), and other authors also assigned carbonaceous chondrites to the H group. Thus, having taken as a basis the uniformity of the total iron content, many researchers have investigated the systematic change in the chemical content in enstatite, bronzite, and carbonaceous chondrites, differing essentially in the degree of iron oxidation. This difference, as is well known, is expressed in the ratio between the various iron forms -- metallic iron, ferrous oxide, and ferrous sulfide. /292

Recently, it was found by Keil and Fredriksson (Ref. 5) that the content of ferrous oxide in the silicate minerals of bronzite and hypersthene chondrites fluctuates within narrow limits in each of these groups. Hence, these authors, and also Suess (Ref. 6) and Craig (Ref. 7) concluded that the data on the different content of various iron forms in each group of chondrites are mainly due to errors in chemical analysis.

In fact, the determination of various iron forms in chondrites is not an easy task, not only because of the difficulties involved in a complete extraction of iron from silicates, but also because of the complexity of selecting for analysis a small representative sample characterizing the inhomogeneous composition of a given meteorite. Therefore, the most reliable determinations of the content of chondrites could, in our opinion, be achieved in those experiments where refined analytical techniques were used in conjunction with the utilization of a larger sample and controlled research on the content of minerals.

The number of such analytical researches can first include the investigations by D'yakonova, Kharitonova (Ref. 8-12) and by Wiik (Ref. 2, 13-24). From the earlier studies, we may single out the analysis of chondrites performed by Prior (Ref. 25-30). We made use of the results of 97 analyses of chondrites, performed by the indicated authors, and also the data supplied by other investigators (Ref. 31-33) concerning three enstatite chondrites.

These results can be represented graphically in a diagram, where the combined content of metallic iron and ferrous sulfide versus the content of ferrous oxide is plotted on the axes. This method of expressing composition, used by a number of authors, enables one to show both the relative abundance of various forms of iron in chondrites and its total content. A similar graph is shown in Figure 1.

In order to make it possible to compare the content of various types of chondrites, the iron content was shown here not in percents of the total sum by weight, but in the form of its ratio to the silicon content (in atomic percents). The symbols for various types of chondrites are shown in the graph.

According to the data of Urey and other authors, the points in the graph should lie on two lines making a 45° angle with the coordinate axes. In the opinion of Keil and others, the points for bronzite, hypersthene (and amphoteric?) chondrites should form segments of vertical straight lines. In reality, however, the points most likely form three branches making various angles with the coordinate axes. The largest angle with the abscissa axis is made by enstatite chondrites of both types. A smaller angle is made by so-called ordinary chondrites consisting of bronzite, hypersthene, and amphoteric chondrites, and the smallest angle is made by the carbonaceous chondrites of all three types. Possibly, each branch in its lower part bends in the direction of increasing content of ferrous oxide.

Thus, according to the available evidence chondrites should, apparently, be divided not into two sequences (with the total content of ferrous oxide being constant) or several separate groups (with the

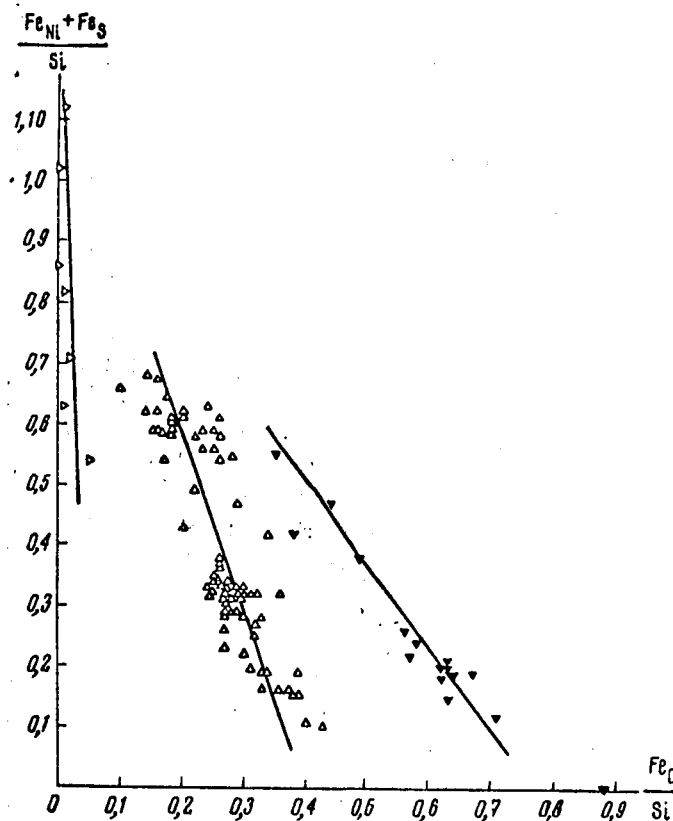


Figure 1

Relation Between Ferrous Oxide and Metallic Iron + Ferrous Sulfide in Chondrites:

- ▷ -- Enstatite chondrites, Δ -- Ordinary chondrites,
▲ -- Carbonaceous chondrites, ▽ -- Renazzo chondrites.

constant content of ferrous oxide), but into three branches having a variable content of both the total iron and its separate forms.

It is also very likely that the contradictions among these three branches will be smoothed out after the scattering of points in each group is decreased as a result of refining the analytical data. In this case, points in each group will concentrate around the average values, and consequently the statements affirming the *constant* content of both the total iron and ferrous oxide within *each group*, and of its *variable* content in *different groups* will turn out to be valid. /293

We may also attempt to study this problem by drawing upon additional data, for instance, the content of nickel in chondrites. Behavior of nickel, a siderophylic element, should clearly be analogous to that of iron. Thus, for example, Anders (Ref. 34), assuming that the total content of iron in chondrites of various groups is constant, considers the nickel content also as constant.

In this case, in the graph showing the correlation between the total iron content and the nickel content in chondrites, there should be no correlation between the indicated quantities within the limits of each group, since the fluctuations in content will be determined by random causes.

On the other hand, if the assumption of constant content of ferrous oxide in each group (with variable total iron content) is valid, then a change in nickel content will be completely determined by the change in metallic iron content. In this case, on the curve showing the relation between the iron and nickel content, one should observe jumps in the transition from one group to another.

One can see in the following graph (Figure 2), which is plotted on the coordinates $Ni/Si - Fe/Si$ from the data based on 100 analyses of chondrites, and also supplemented by the results of Wiik for 5 294 carbonaceous chondrites (Ref. 35), that the points linking the content of nickel and iron in ordinary chondrites -- disregarding the scatter -- are essentially located along a straight line.

In enstatite chondrites (according to the data of 6 analyses), the dependence of nickel content on iron content is considerably weaker. As to the carbonaceous chondrites, nickel content in each of their groups is almost constant, i.e., it does not depend on iron content. However, the points corresponding to average composition of each group of carbonaceous chondrites show the largest dependence of nickel content on iron content. The obtained results are confirmed by analogous data of Anders (Ref. 34), and lead to the conclusion that the nickel content in chondrites is also likely to indicate successive changes of composition within each group (possibly, with the exception of carbonaceous chondrites).

On the whole, it is perfectly clear that the relative content of nickel changes in different ways in enstatite, ordinary, and carbonaceous chondrites. Moreover, it is noteworthy that ordinary chondrites occupy the intermediate position between the enstatite and carbonaceous ones, both in the nature of the variation in the total iron content with the degree of its oxidation, and in the nature of the variation of relative nickel content.

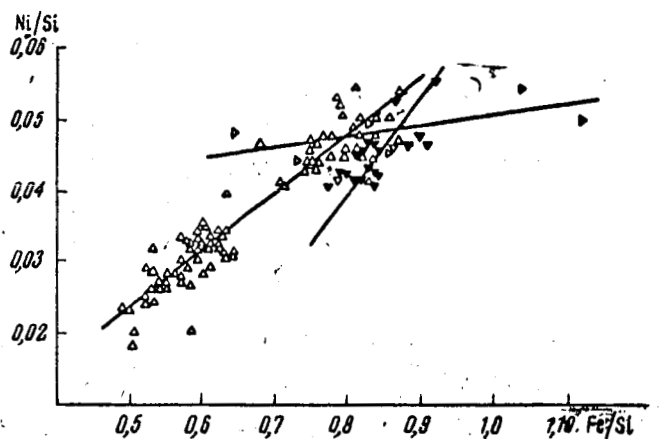


Figure 2

Relation Between the Nickel and Iron Content in Chondrites.

For notations see Figure 1.

We shall now discuss the behavior of lithophylic elements in the silicate phase of meteorites. During recent years a number of articles have been published devoted to the determination of many elements in meteorites. We have made use of the data contained in these articles on the content of alkali, alkali-earth, rare-earth, and other lithophylic elements in meteorites of different types.

The content of the following 37 elements was studied: Li [36-39],* Na [2, 13-24, 40-42], K [2, 8-24, 40-45], Rb [46-49], Cs [46, 48, 50], Be [51], Mg, Ca [2, 8-30, 52], Sr [36, 47, 49, 53], Ba [54-56], Al, Si [2, 8-30, 52], Ti [2, 8-30, 52, 57, 58], V [57, 59], Cr [2, 8-30, 52, 57], Mn [2, 8-30, 52, 57, 58], Sc [36, 60-63], Y, La, Ce, Pr, Nd, Sm [62-64], Eu [61-64], Gd, Tb, Dy, Ho, Er, Tu, Yb, Lu [62-64], Zr [36, 65-67], Hf [65, 66], Ta [68, 69], Th [45, 70-72], U [55, 71-76]. To compare the content of the silicate phase of meteorites of various types, the data were expressed in the form of the ratio of the number of atoms of an element to the number of atoms of silicon ($\text{Si} = 10^6$).

From all the types of meteorites we have chosen only those in which the majority of the elements indicated above were determined, namely: chondrites -- enstatite (of Indarkh type), bronzite, hypersthene, amphoteric, carbonaceous (of Orgueil type), carbonaceous (of Migey and Felix type); anchondrites, calcium-rich, -- eucrites, naclites; achondrites, calcium-poor, -- obrites, diogenites; pallasites (of

* Numbers in brackets pertain to references.

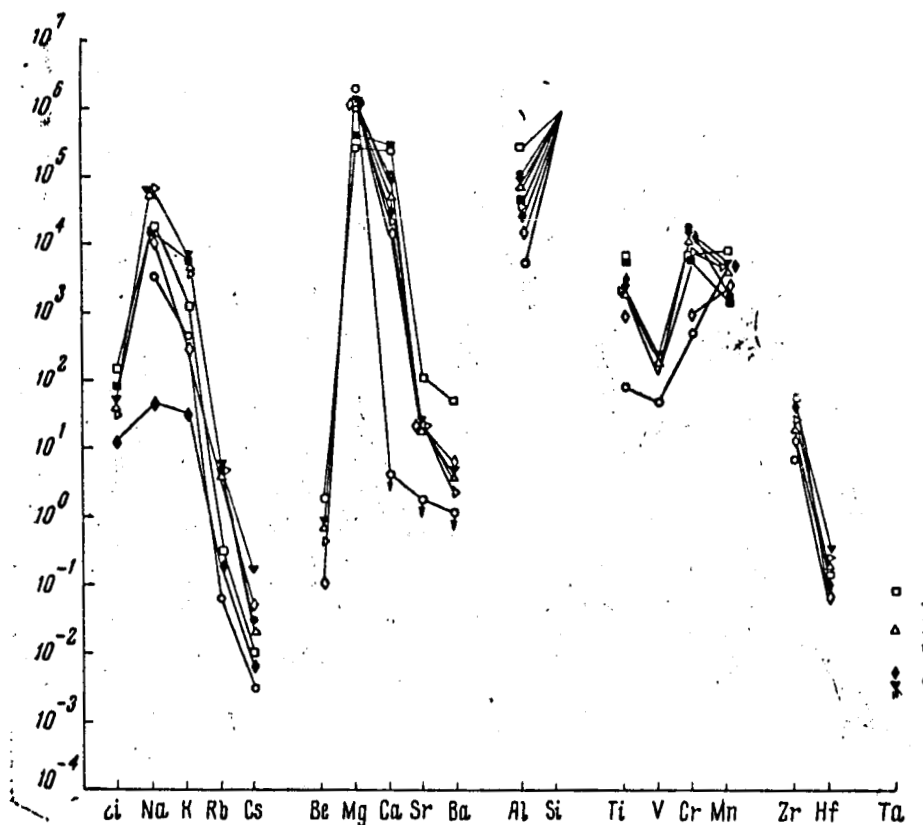


Figure 3

Atomic Abundance of Alkali, Alkali-Earth and Other Lithophylic Elements in the Silicate Phase of Meteorites ($Si = 10^6$):

▷ - Enstatite chondrites, Δ - Ordinary chondrites, ◀ - Carbonaceous chondrites; □ - Eucrites, ■ - Naclites; ■ - Obrites, ◆ - Diogenites; ○ - Pallasites, ● - Mesosiderites.

Pallasitic iron type), mesosiderites (except Bencubbin).

Atomic abundance of the elements, separated into groups, is shown in the graphs (Figures 3, 4) in a logarithmic scale.

The first fact which attracts our attention when we study the graphs is the exceptional homogeneity of the content of ordinary chondrites, which once again emphasizes their close proximity. With respect to the content of the majority of elements, they lie between enstatite and

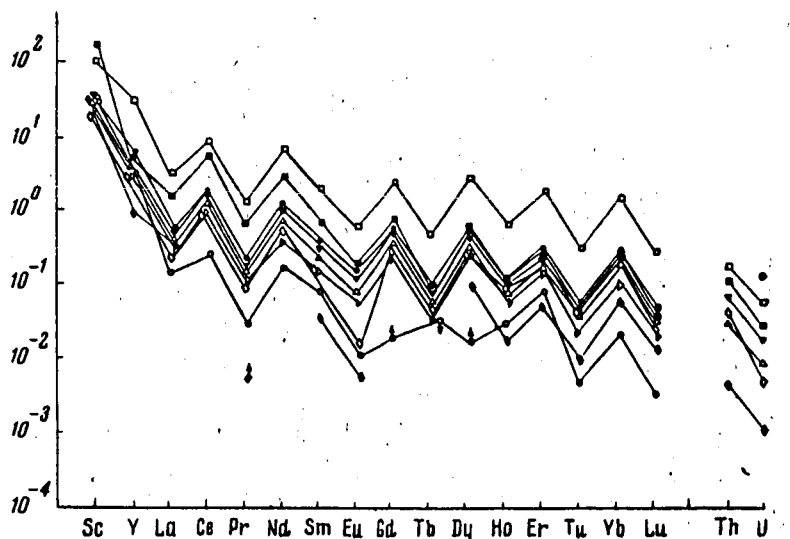


Figure 4

Atomic Abundance of Scandium, Itrium, Lanthanides and Actinides in the Silicate Phase of Meteorites ($Si = 10^6$)

For notations see Figure 3.

carbonaceous chondrites. Carbonaceous chondrites, differing from the ordinary ones in the content of all the indicated elements, differ as far as the content of various groups is concerned. This refers mainly to alkali metals, whose concentration successively changes in progressing from chondrites of the Orgueil type to chondrites of Migey and Felix types. Enstatite chondrites differ from ordinary and carbonaceous ones, but chondrites of Hvittis type could not be compared with chondrites of Indarkh type, because of the lack of data on the content of the majority of elements.

From the data presented on the content of chondrites, one can see a direct connection between the groups within each branch, in particular in carbonaceous and ordinary chondrites. /296

At the present time, however, one cannot draw any conclusion about the processes of transition from one branch of chondrites to another. Specifically, a change in the composition of carbonaceous chondrites does not lead to the composition of ordinary chondrites, as is sometimes thought.

Possibly, it is more plausible to assume that all the three types of chondrites -- enstatite, ordinary, and carbonaceous -- had a common origin.

Calcium-rich achondrites -- eucrites and naclites -- differ from chondrites not only in the content of the basic components of the silicate phase -- calcium, aluminum and magnesium -- but also in the concentration of alkali and alkali-earth elements, and in an increased content of rare-earth elements.

Calcium-poor achondrites -- obrites and diogenites -- are in their content closer to chondrites, but when compared with the latter, a decreased content of all lithophylic elements is found.

The silicate phase of pallasites is distinguished by a high relative content of magnesium, and a decreased (as compared with chondrites) content of the other lithophylic elements.

The composition of the silicate phase of mesosiderites is closest to the composition of carbonaceous chondrites.

The general conclusion which may be drawn from the examination of the data presented is that the peculiarities in the chemical composition of the silicate phase of meteorites cannot be explained by any single process of fractionation -- as, for example, the loss of volatile elements. As follows from factual material, one cannot find any direct transition between carbonaceous, ordinary, and enstatite chondrites.

One may assume that the differentiation of meteoritic matter has passed through several stages: First its division into the principal groups of chondrites, and then (owing to the fractionation of the composition of these groups) leading to the final formation of other types of meteorites -- achondrites, stony-iron, and iron meteorites.

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REFERENCES

1. Urey, H.C., Craig, H. The Composition of the Stony Meteorites and the Origin of the Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 4, No. 1-2, 1953.
2. Wiik, H.B. The Chemical Composition of Some Stony Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 9, No. 5-6, 1956.
3. Ringwood, A.E. Chemical and Genetic Relationships Among Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 24, No. 3-4, 1961.

4. Mason, B. The Classification of Chondritic Meteorites. Amer. Mus. Novit., No. 2085, 1962.
5. Keil, K., Fredriksson, K. The Iron, Magnesium, and Calcium Distribution in Co-existing Olivines and Rhombic Pyroxenes of Chondrites. J. Geophys. Res., Vol. 69, No. 16, 1964.
6. Suess, H.E. The Urey-Craig Groups of Chondrites and their States of Oxidation. In the book: Isotopic and Cosmic Chemistry. North Holland Publ. Co., Amsterdam, 1964.
7. Craig H. Petrological and Compositional Relationships in Meteorites. In the book: Isotopic and Cosmic Chemistry. North Holland Publ. Co., Amsterdam, 1964.
8. D'yakonova, M.I., Kharitonova, V. Ya. Rezul'taty khimicheskogo analiza nekotorykh kamennykh i zheleznykh meteoritov kollektzii AN SSSR (Results of the Chemical Analysis of Some Stony and Iron Meteorites from the Collection of the Academy of Sciences of USSR). Meteoritika, No. 18, 1960.
9. D'yakonova, M.I., Kharitonova, V. Ya. Khimicheskii sostav 18 kamennykh meteoritov iz kollektzii Akademii Nauk SSSR (Chemical Composition of 18 Stony Meteorites from the Collection of the Academy of Sciences of USSR). Meteoritika, No. 21, 1961.
10. D'yakonova, M.I., Kharitonova, V. Ya. Khimicheskii sostav khondr meteoritov Nikol'skoye i Siryatov (Chemical Composition of Chondrules of Nikel'skoe and Siryatov Meteorites). Meteoritika, No. 22, 1962.
11. *
12. Kharitonova, V. Ya. Rezul'taty khimicheskogo analiza desyati kamennykh meteoritov iz kollektzii AN SSSR (Results of the Chemical Analysis of Ten Stony Meteorites from the Collection of the Academy of Sciences of USSR). Meteoritika, No. 26, 1965.
13. Mason, B., Wiik, H.B. The Tomhannock Creek, New York, Chondrite. Mineral Mag., Vol. 32, No. 250, 1960.
14. Mason, B., Wiik, H.B. The Selma, Alabama, Chondrite. Amer. Mus. Navit. No. 2010, 1960.
15. Mason, B., Wiik, H.B. The Miller, Arkansas, Chondrite. Geochim. et Cosmochim.*
16. Mason, B., Wiik, H.B. The Kyushu, Japan, Chondrite. Geochim. et Cosmochim. Acta, Vol. 21, No. 3-4, 1961.
17. Mason, B., Wiik, H.B. The Holbrook, Arizona, Chondrite. Geochim. et Cosmochim. Acta, Vol. 21, No. 3-4, 1961.
18. Mason, B., Wiik, H.B. The Composition of the Ottawa, Chateau-Renard, Mocs, and New Concord Meteorites. Amer. Mus. Novit., No. 2069, 1961.

* Translator's note: Illegible in original text.

19. Mason, B., Wiik, H.B. The Renazzo Meteorite. Amer. Mus. Novit., No. 2106, 1962.
20. Mason, B., Wiik, H.B. Description of Two Meteorites: Karoonda and Erakot. Amer. Mus. Novit., No. 2115, 1962.
21. Mason, B., Wiik, H.B. The Composition of the Richardton, Estacado, and Knyahinya Meteorites. Amer. Mus. Novit., No. 2154, 1963.
22. Mason, B., Wiik, H.B. The Amphoterites and Meteorites of Similar Composition. Geochim. et Cosmochim. Acta, Vol. 28, No. 4, 1964.
23. Kvasha, L.G., Wiik, H.B. Nekotoryye dopolnitel'nyye dannyye ob uglistom khondrite Staroye Boriskino (Some Additional Data on the Carbonaceous Chondrite Staroye Boriskino). Meteoritika, No. 24, 1964.
24. Keil, K., Mason, B., Wiik, H.B., Fredriksson, K. The Chainpur Meteorite. Amer. Mus. Novit., No. 2173, 1964.
25. Prior, G.T. The Meteorites of Uwet, Kota Kota and Angela; Redeterminations of Nickel and Iron in the Baroti and Wittekrantz Meteoric Stones. Mineral Mag., Vol. 17, No. 80, 1914.
26. Prior, G.T. The Meteorite Stones of Launton, Warhreccan, Cronstad, Daniel's Kuil, Khairpur and Soko-Banja. Mineral Mag., Vol. 18, No. 83, 1916.
27. Prior, G.T. On the Chemical Composition of the Meteorites Amana (Homestead) and Eagle Station. Mineral. Mag., Vol. 18, No. 85, 1918.
28. Fletcher, L., Prior, G.T. The Meteoric Stone Seen to Fall Near Crumlin County, Antrim, on Sept. 13, 1902. Mineral. Mag., Vol. 19, No. 93, 1921.
29. Prior, G.T. On the South African Meteorites, Mount Aylif and Simondium, and the Chemical Composition of the Meteorites, Adare and Ensisheim. Mineral. Mag., Vol. 19, No. 93, 1921.
30. Prior, G.T. The Meteoric Stone of Lake Brown, Western Australia. Mineral. Mag., Vol. 22, No. 127, 1929.
31. Borgstroem, L.H. Die Meteoriten von Hvittis und Marjalahti (The Meteorites of Hvittis and Marjalahti). Bull. Comm. Geol. Finland, No. 14, 1903.
32. Lacroix, A. La composition de la météorite tombée à Saint-Sauveur (Haute-Garonne) en 1914 (The Composition of the Meteorite Which Fell at Saint-Sauveur [Haute-Garonne] in 1914). Compt. Rend., Vol. 177, 1923.
33. Dawson, K. R., Maxwell, J.A., Parsons, D.E. A Description of the Meteorite Which Fell Near Abee, Alberta, Canada. Geochim. et Cosmochim. Acta, Vol. 21, No. 1-2, 1960.
34. Anders, E. Origin, Age, and Composition of Meteorites. Space Sci. Revs, Vol. 3, No. 5-6, 1964.
35. Mason B. The Carbonaceous Chondrites. Space Sci. Revs, Vol. 1, No. 4, 1963.
36. Pinson, W.H., Ahrens, L.H., Franck, M.L. The Abundances of Li, Sc, Sr, Ba and Zr in Chondrites and Some Ultramafic Rocks. Geochim. et Cosmochim. Acta, Vol. 4, No. 5, 1953.

37. Fireman, E.L., Schwarzer, D. Measurement of Li^6 , He^3 and H^3 in Meteorites and its Relation to Cosmic Radiation. *Geochim. et Cosmochim. Acta*, Vol. 11, No. 4, 1957.
38. Shima, Makoto, Honda, M. Isotopic Abundance of Meteoritic Lithium. *J. Geo-phys. Res.*, Vol. 68, No. 9, 1963.
39. Krankovsky, D., Mueller, O. Isotopenhaeufigkeit und Konzentration des Lithiums in Steinmeteoriten (Isotopic Abundance and Concentration of Lithium in Stony Meteorites). *Geochim. et Cosmochim. Acta*, Vol. 28, No. 11, 1964.
40. Edwards, G., Urey, H.C. Determination of Alkali Metals in Meteorites by a Distillation Process. *Geochim. et Cosmochim. Acta*, Vol. 7, No. 3-4, 1955.
41. Edwards, G. Sodium and Potassium in Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 8, No. 5-6, 1955.
42. Easton, A.J., Lovering, J.F. Determination of Small Quantities of Potassium and Sodium in Stony Meteoritic Material, Rocks and Minerals. *Analyt. Chim. Acta*, Vol. 30, No. 6, 1964.
43. Geiss, J., Hess, D.C. Argon-potassium Ages and the Isotopic Composition of Argon from Meteorites. *Astrophys. J.*, Vol. 127, No. 1, 1958.
44. Kirsten, T., Krankowsky, D., Zaehring, J. Edelgas- und Kalium-Bestimmungen an einer grösseren Zahl von Steinmeteoriten (Determinations of Noble Gases and Calcium in a Large Number of Stony Meteorites). *Geochim. et Cosmochim. Acta*, Vol. 27, No. 1, 1963.
45. Rowe, M.W., Dilla, M.A., van, Anderson, E.C. On the Radioactivity of Stone Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 27, No. 10, 1963.
46. Webster, R.K., Morgan, J.W., Smales, A.A. Caesium in Chondrites. *Geochim. et Cosmochim. Acta*, Vol. 15, No. 1-2, 1958.
47. Gast, P.W. The Isotopic Composition of Strontium and the Age of Stony Meteorites. I. *Geochim. et Cosmochim. Acta*, Vol. 26, No. 9, 1962.
48. Smales, A.A., Hughes, T.C., Mapper, D., McInnes, C.A.J., Webster, R.K. The Determination of Rubidium and Caesium in Stony Meteorites by Neutron Activation Analysis and by Mass Spectrometry. *Geochim. et Cosmochim. Acta*, Vol. 28, No. 2, 1964.
49. Pinson, W.H., Schnetzler, C.C., Beiser, E., Fairbairn, H.W., Hurley, P.M. Rb-Sr Age of Stony Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 29, No. 5, 1965.
50. Gast, P.W. Alkali Metals in Stone Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 19, No. 1, 1960.
51. Sill, C.W., Willis, C.P. The Beryllium Content of Some Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 26, No. 11, 1962.
52. Yavnel'A.A., D'yakonova, M.I. Khimicheskiy sostav meteoritov (Chemical Composition of Meteorites). *Meteoritika*, No. 15, 1958.

53. Erlank, A.J., Willis, J.P. The Zirconium Content of Chondrites and the Zirconium-hafnium Dilemma. *Geochim. et Cosmochim. Acta*, Vol. 28, No. 11, 1964.
54. Hamaguchi, H., Reed, G., Turkevich, A. Uranium and Barium in Stone Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 12, No. 4, 1957.
55. Reed, G.W., Kigoshi, K., Turkevich, A. Determinations of Concentrations Heavy Elements in Meteorites by Activation Analysis. *Geochim. et Cosmochim. Acta*, Vol. 20, No. 2, 1960.
56. Moore, C.B., Brown, H. Barium in Stony Meteorites. *J. Geophys. Res.*, Vol. 68, No. 14, 1963.
57. Lovering, J.F., Nichiporuk, W., Chodos, A., Brown, H. The Distribution of Gallium, Germanium, Cobalt, Chromium, and Copper in Iron and Stony-Iron Meteorites in Relation to Nickel Content and Structure. *Geochim. et Cosmochim. Acta*, Vol. 11, No. 4, 1957.
58. Moore, C.V., Brown, H. The Distribution of Manganese and Titanium in Stony Meteorites. *Geochim. et Cosmochim. Acta*, Vol. 26, No. 4, 1962.
59. Kemp, D.M., Smales, A.A. The Determination of Vanadium in Rocks and Meteorites by Neutron-Activation Analysis. *Analyt. Chim. Acta*, Vol. 23, No. 5, 1960.
60. Kemp, D.M., Smales, A.A. The Determination of Scandium in Rocks and Meteorites by Neutron-Activation Analysis. *Analyt. Chim. Acta*, Vol. 23, No. 5, 1960.
61. Bate, G.L., Potratz, H.A., Huizenga, J.R. Scandium, Chromium and Europium in Stone Meteorites by Simultaneous Neutron Activation Analysis. *Geochim. et Cosmochim. Acta*, Vol. 18, No. 1-2, 1960.
62. Schmitt, R.A., Smith, R.H., Lasch, J.E., Mosen, A.W., Olehy, D.A., Vasilevscis, J. Abundances of the Fourteen Rare-earth Elements, Scandium, and Yttrium in Meteoritic and Terrestrial Matter. *Geochim. et Cosmochim. Acta*, Vol. 27, No. 6, 1963.
63. Schmitt, R.A., Smith, R.H., Olehy, D.A. Rare-earth Yttrium and Scandium Abundances in Meteoritic and Terrestrial Matter. II. *Geochim. et Cosmochim. Acta*, Vol. 28, No. 1, 1964.
64. Haskin, L., Gehl, M.A. The Rare-earth Distribution in Sediments. *J. Geophys. Res.*, Vol. 67, No. 6, 1962.
65. Setser, J.L., Ehmann, W.D. Zirconium and Hafnium Abundances in Meteorites, Tektites and Terrestrial Materials. *Geochim. et Cosmochim. Acta*, Vol. 28, No. 6, 1964.
66. Merz, E., Schrage, E. Aktivierungsanalytische Bestimmung des Zr-Hf-Verhältnisses in Steinsmeteoriten und Gesteinen. (Activation Analysis Determination of Zr-Hf Relations in Stony Meteorites and Rocks). *Geochim. et Cosmochim. Acta*, Vol. 28, No. 11, 1964.
67. Schmitt, R.A., Bingham, E., Chodos, A.A. Zirconium Abundances in Meteorites and Implications to Nucleosynthesis. *Geochim. et Cosmochim. Acta*, Vol. 28, No. 12, 1964.
68. Atkins, D.H., Smales, A.A. The Determination of Tantalum and Tungsten in Rocks and Meteorites by Neutron Activation Analysis.

- Analyst. Chim. Acta, Vol. 22, No. 5, 1960.
69. Ehmann, W.D. On Some Tantalum Abuncances in Meteorites and Tektites. *Geochim. et Cosmochim. Acta*, Vol. 29, No. 1, 1965.
 70. Bate, G.L., Huizenga, J.R., Potratz, H.A. Thorium in Stone Meteorites by Neutron Activation Analysis. *Geochim. et Cosmochim. Acta*, Vol. 16, No. 1-3, 1959.
 71. Lovering, J.F., Morgan, J.W. Uranium and Thorium Abundances in Stony Meteorites. 1. The Chondritic Meteorites. *J. Geophys. Res.*, Vol. 69, No. 10, 1964.
 72. Morgan, J.W., Loevring, J.F. Uranium and Thorium Abundances in Stony Meteorites. 2. The Achondritic Meteorites. *J. Geophys. Res.*, Vol. 69, No. 10, 1964.
 73. Koenig, H., Waenke, H. Uranbestimmungen an Steinmeteoriten mittels Neutronenaktivierung über die Xenon-Isotope 133 und 135 (Determination of Uranium in Stony Meteorites by Neutron Activation on the Xenon 133 and 135 Isotopes). *Z. Naturforsch.*, Vol. 14a, No. 10, 1959.
 74. Starik, I. Ye., Shats, M.M. Novyye dannyye po opredeleniyu sod-erzhaniya urana v meteoritakh (New Data on the Determination of Uranium Content in Meteorites). *Meteoritika*, No. 18, 1960.
 75. Goles, G.G., Anders, E. Abundances of Iodine, Tellurium and Uranium in Meteorites. *Goechim. et Cosmochim. Acta*, Vol. 26, No. 7, 1962.
 76. Reed, G.W. Heavy Elements in the Pantar Meteorite. *J. Geophys. Res.*, Vol. 68, No. 11, 1963.

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